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ONE FOOT HYBRID SUPERCONDUCTING DIPOLE MAGNET

R. Yamada, H. Ishimoto and M.E. Price

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INTRODUCTION

In many existing projects where superconducting dipole magnets are going to be used, the target field value is considered to be $40 \sim 45$ kG. To have a larger margin and also to get higher energy, the development of 60 kG magnets is now going on in some laboratories. For example, in the POPAE project, the designed field is 60 kG. One way to get a higher field is to use a superconducting material with a higher J_c value, such as Nb_3Sn. However, at present, there are still mechanical problems with this material which is brittle and hard to bend without losing high field characteristics. 60 kG is the turning point where, at present, NbTi material is most practical but, in the future, will be less attractive. As a first step to 60 kG using readily available materials, we constructed a small one foot dipole magnet with 23 strand NbTi cable. We made a one layer coil and inserted it into an existing Energy Doubler one foot model magnet. The magnet was excited up to 55.4 kG.

DESIGN AND CONSTRUCTION

We used existing products and materials as much as possible. As an outer coil, E1-31 (an Energy Doubler one foot model magnet) was used. The inner coil was designed and constructed to get as high a field as possible, and field quality was not seriously taken into account. The cross-sectional view of the whole magnet is given in Fig. 1.

The cable used was leftover from an E/D model magnet. The present inner coil has a smaller diameter, which requires a more keystoned cable. For this purpose, a narrow strip of B-stage glass tape 7 mil. thick and one-eighth inch wide was put on the outside edge as a shim during winding. The same winding and curing techniques which were developed for the E/D magnets were employed.

Conductor configuration is summarized in Table 1. The first shell was wound to have a splice at the end opposite the current leads, which caused an extra half turn on both top and bottom coils. The second and third shells are those of E1-31. To avoid having the highest field at the end portion, the inner coil is made longer than the length of E1-31, as shown in Fig. 2. The field calculation was made with the computor program GFUN2D, which was available in the TSO system of the IBM 370 at ANL[1]. The highest field occurs at the innermost turn of the first shell. According to the calculation, it is about 6~7% higher than that at the center.

First the two halves of the inner coil were supported on a stainless steel pipe and a stainless key was used for positioning. The pipe had holes and grooves for cooling and strips of kapton tape were used for insulation. Then, while being held with hose clamps, the coil halves were banded with 1" wide epoxy coated glass tape and then cured. Finally, the outside diameter of these glass tape bands was machined with a lathe to a predetermined size, giving a desired interference fitting between the coil structure and the aluminum pipe. The actual interference was 5 mils at room temperatures. In assembly, the two half coils were shrunk to fit into an aluminum pipe for mechanical support. Usually the fitting process is made by cooling the coil structure to 77 K using liquid nitrogen. In our case, to make the process easier, we not only cooled the coil but we also heated the aluminum pipe to roughly 100° C (clearance before fitting was 4 mils). It is important to proceed very rapidly, otherwise the outside pipe is cooled and shrinks before the coil is in place. Judging from an independent measurement of shrinkage on the coil structure and the aluminum pipe, the interference at 4.2 K is estimated to be 6~8 mils. In detailed calculations, it corresponds to a precompression of about $5\sim7 \times 10^8$ dyn/cm^2. After putting some insulation on the outside of the aluminum pipe, the inner coil was installed inside E1-31 and iron was placed on the outside. To prevent relative motion between two coils, the stainless inner bore was connected to the iron with aluminum rods.

TEST RESULTS

The outer coil (E1-31) and inner coil were connected in series and excited. A search coil and integrator system was used to measure the center field. It was calibrated with a standard NMR magnetometer. The Training curve is shown in Fig. 3. After 6 quenches, the field went up to 55 kG. Fig. 4 gives short sample curves and load lines for both inside and outside coils. Quenching, as expected, always happened in the inner coil. The highest field point in the coil is 6~7% higher than the center field in the calculation. The highest center field the magnet obtained, B_{max} = 55.4 kG, corresponds to roughly 94% of short sample limit. The ramp rate dependence of B_{max} is unexpectedly flat up to 6.5 kG/sec, (150 Gev/sec), as shown in Fig. 5. This is the first coil we wound by ourselves and the conductor positioning was not as good as we expected. We took much care to avoid relative movement between the coils, but we are not sure our support system was good enough. To investigate the effect of iron saturation, a transfer factor was measured, especially at high field. Saturation starts above 20 kG and roughly 2% iron saturation appears at 55 kG, as shown in Fig. 6. This number can probably be reduced with a bigger iron configuration. In the design of this magnet, we did not pay much attention to pulsed operation. Therefore, we used thick aluminum and stainless steel metal pipes for mechanical support. To check any eddy current effect in these metals, the ramp rate dependence of ac loss was measured and is given in Fig. 7. This effect does not seem to be serious at least in this small magnet. The maximum field dependence of ac loss is given in Fig. 8. It is from two to three times larger than that for other 1 foot magnets, but our magnet contains only 1.5 times as much conductor. Interestingly, the loss data formed two lines instead of one. The location of any particular data point seemed to be random, but points on both lines repeated and there were no intermediate points. This suggests the possibility of movement or twisting within the magnet that results in different configuration with distinct losses.

This magnet was constructed with existing products and does not have iron laminations large enough to reach 60 kG. Even so, it reached over 55 kG, which is almost 95% of short sample limit. From this experience, we could get a field of 60 kG with an optimized 3 shells design.

ACKNOWLEDGEMENTS

We express our gratitude to the personnel in the magnet facility for suggestions during winding. Also, we would like to thank Mr. L. Turner of ANL for using the GFUN.

REFERENCE

[1] R.J. Lari: Proc. 5th Int. Conf. on Magnet Technology, 244 (1975).

Table 1

Conductor Placement Data

	θ (start)	θ (finish)	i.d. (in)	o.d. (in)	turns/coil
1st shell	0	63.1°	1.750	2.378	17.5
2nd shell	0	73.1°	3.000	3.628	34
3rd shell	0	37.7°	3.670	4.298	21

1' Hybrid Magnet

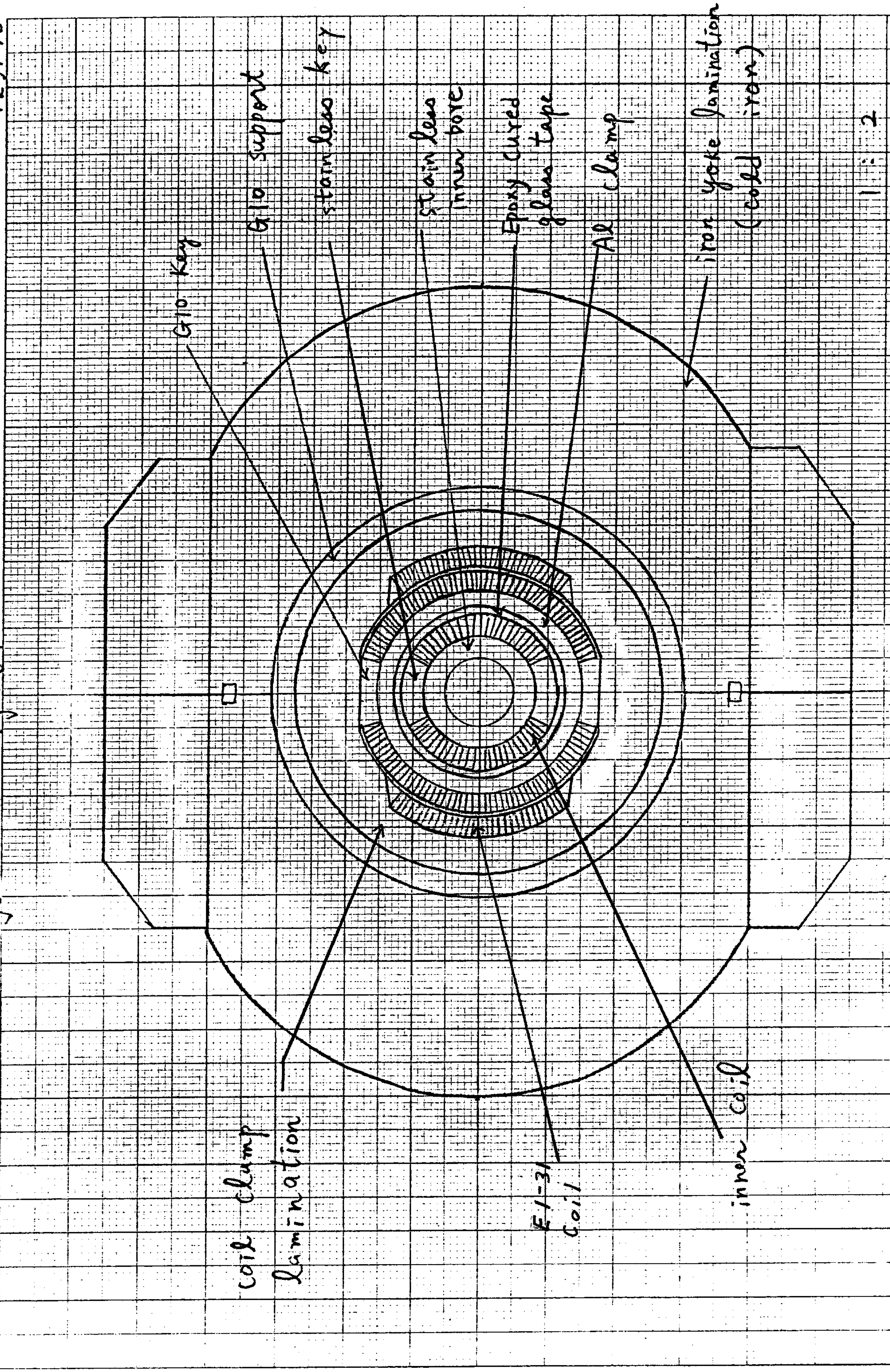


Fig 1. Cross Section of One Foot Hybrid Magnet

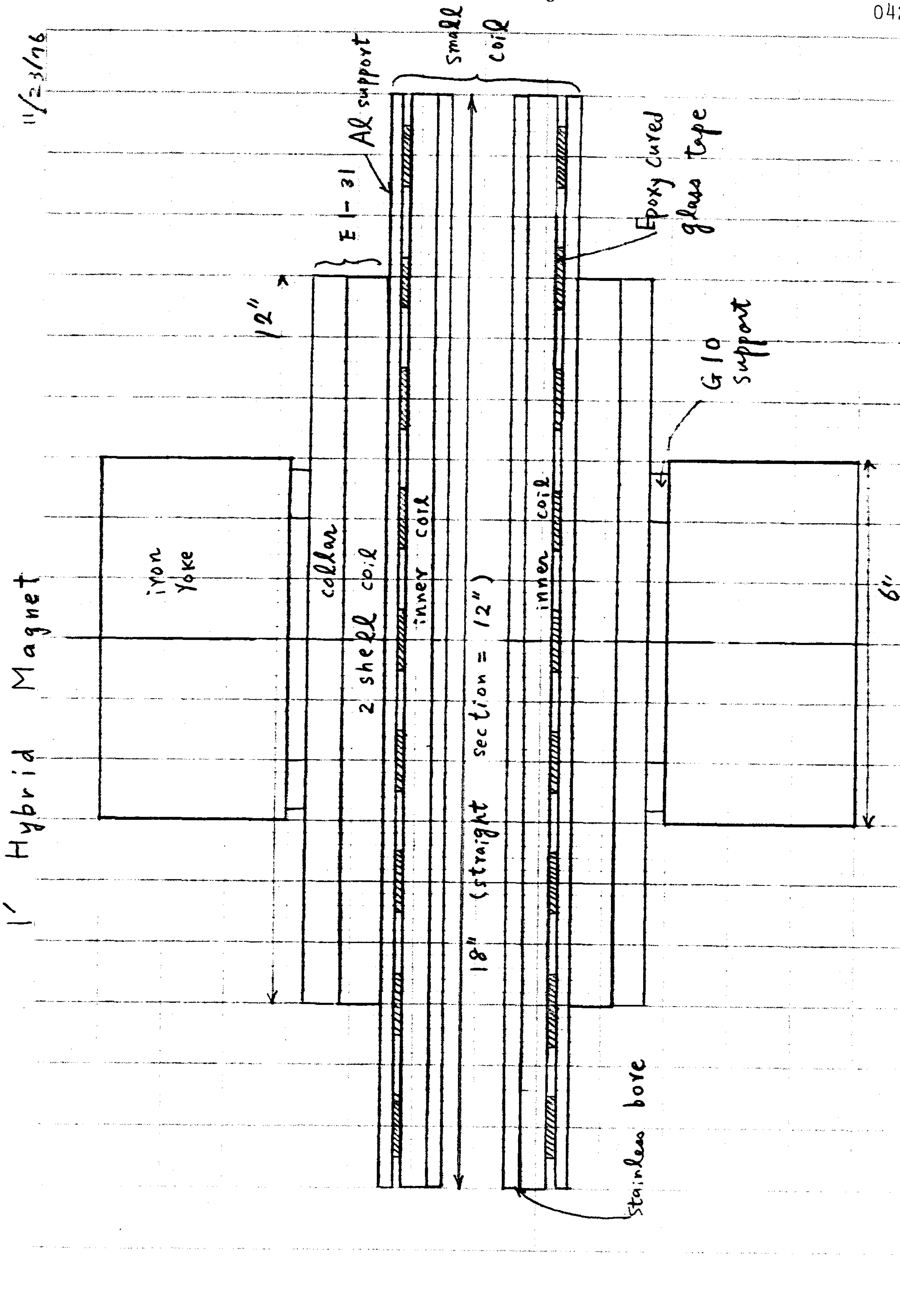
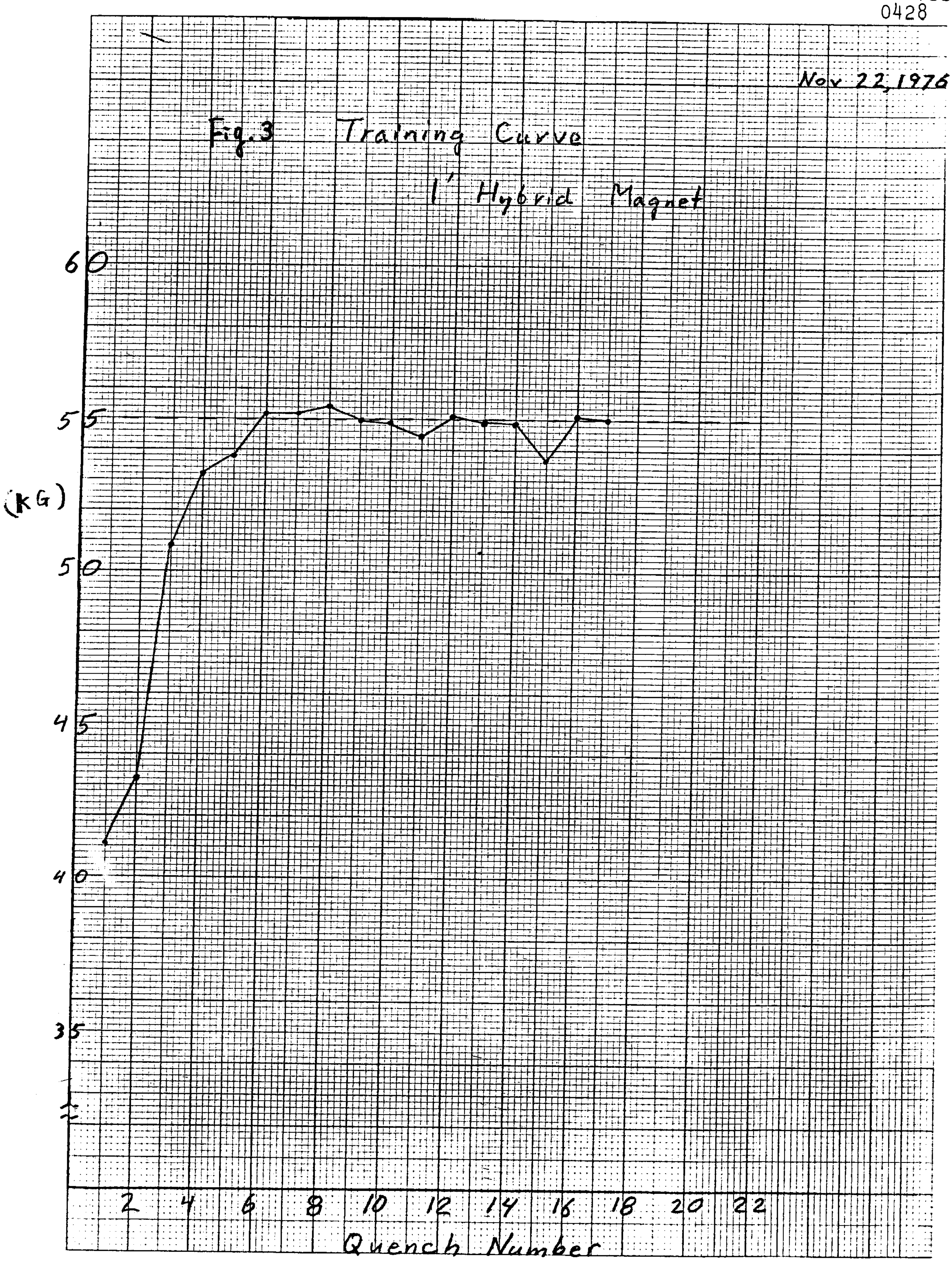


Fig 2 Longitudinal Cross Section of One Foot Hybrid Magnet


Nov 22, 1976
Fig. 3 Training Curve
1" Hybrid Magnet
60
55
(KG)
50
45
40
35
2
4
6
8
10
12
14
16
18
20
22
Quench Number

11/22/76

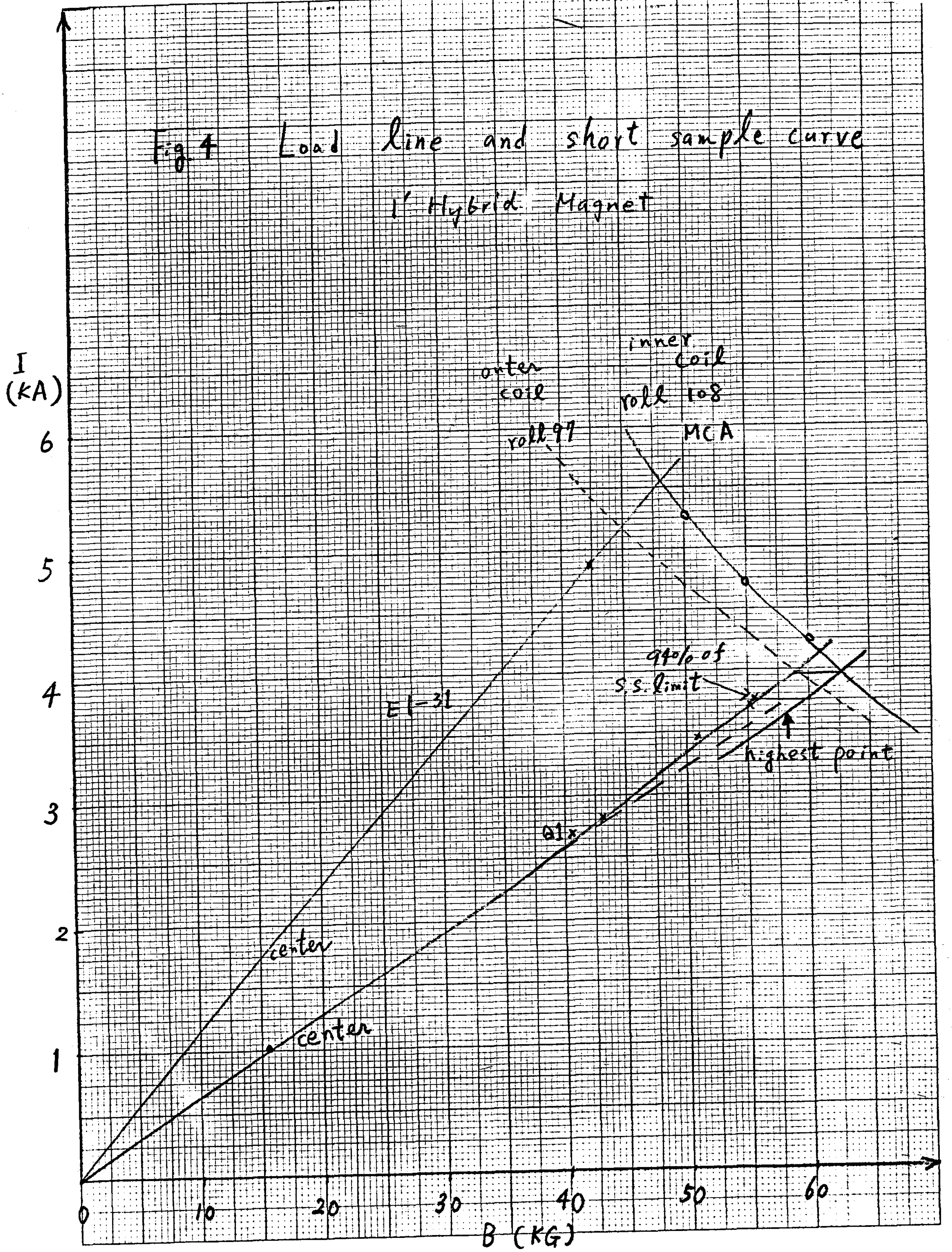


Fig. 4 Load line and short sample curve
1' Hybrid Magnet
I (kA)
6
5
4
3
2
1
outer coil
roll 97
inner coil
roll 108
MCA
94% of
S.S. limit
highest point
E1-31
Q1
center
center
0
10
20
30
40
50
60
B (KG)

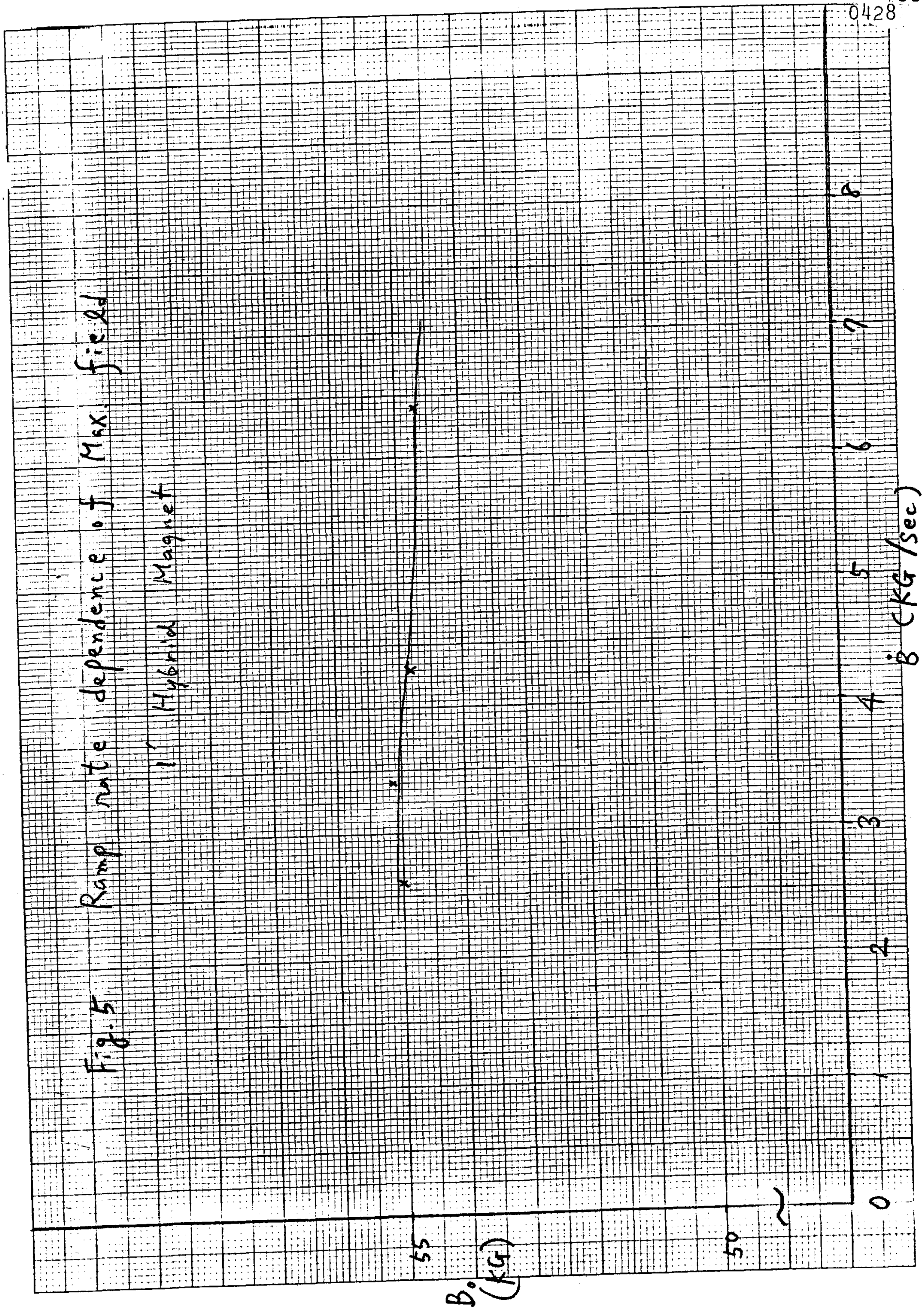
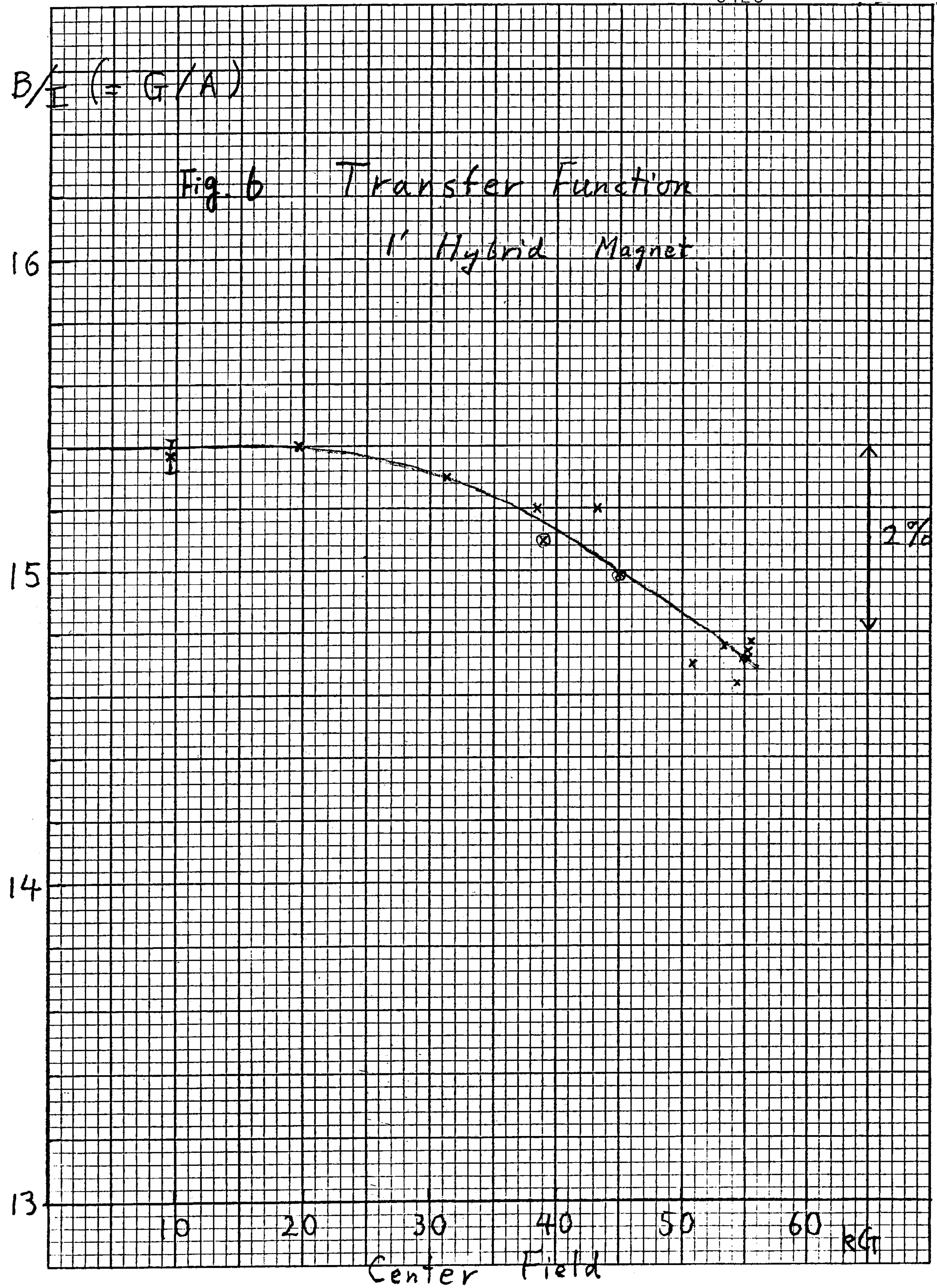


Fig. 5 Ramp rate dependence of Max. field
1' Hybrid Magnet


B/I (= G/A)
Fig. 6 Transfer Function
1' Hybrid Magnet
16
15
14
13
2%
10
20
30
40
50
60
KG
Center Field

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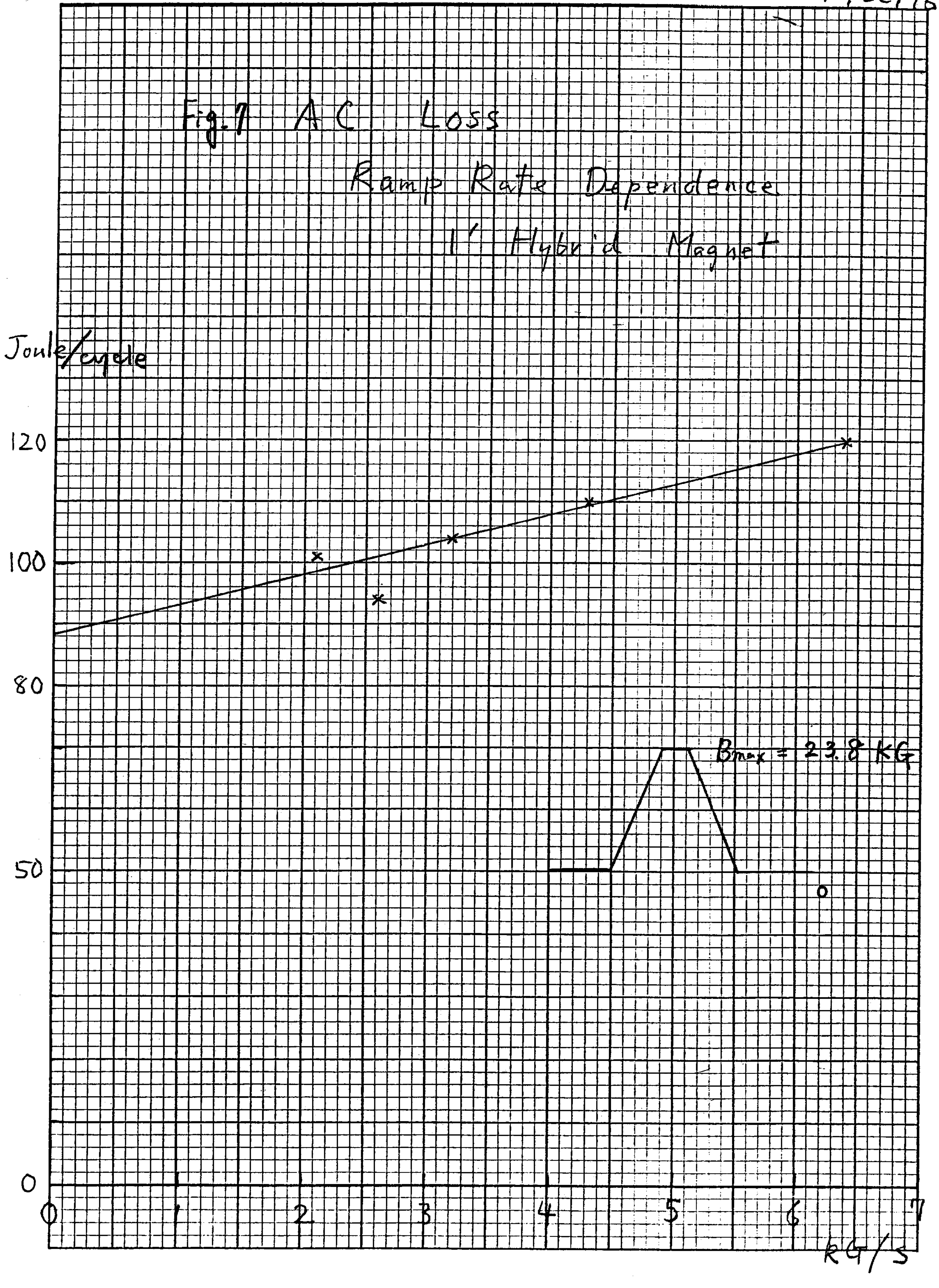

Fig. 7 AC Loss
Ramp Rate Dependence
1' Hybrid Magnet

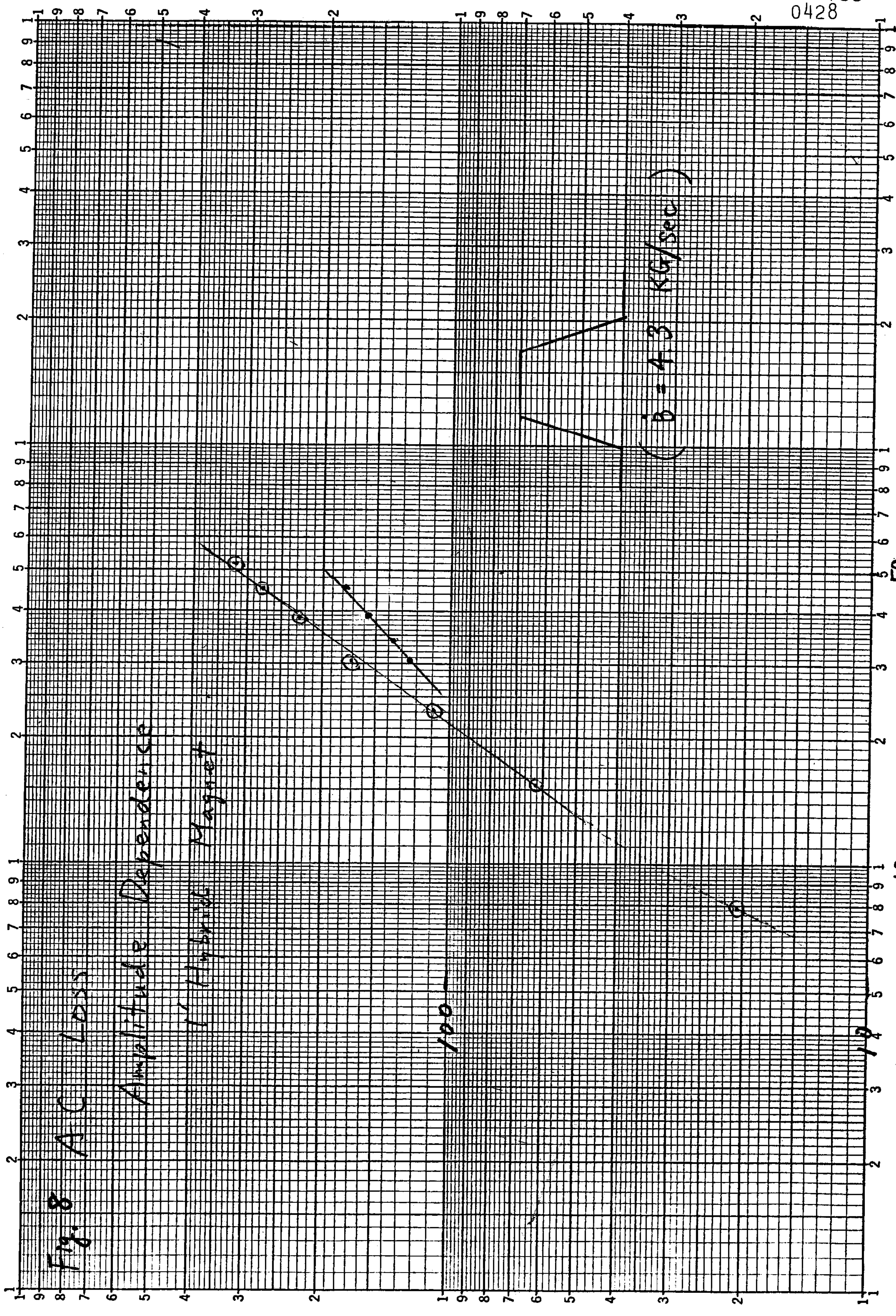
Fig. 8 AC Loss
Amplitude Dependence
(Hybrid Magnet
100
10
50
100
B max (KG)
(Ḃ = 43 KG/sec)